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No. 9.

SCIENTIFIC MEMOIRS

BY

OFFICERS OF THE MEDICAL AND SANITARY DEPARTMENTS

OF THE

GOVERNMENT OF INDIA.

SECOND REPORT OF THE ANTI-MALARIAL OPERATIONS AT MIAN MIR, 1901-1903.

BY

LIEUT. S. R. CHRISTOPHERS, M.B., I.M.S.

(*On special duty.*)

ISSUED UNDER THE AUTHORITY OF THE GOVERNMENT OF INDIA
BY THE SANITARY COMMISSIONER WITH THE GOVERNMENT
OF INDIA, SIMLA.

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SECOND REPORT OF THE ANTI-MALARIAL OPERATIONS AT MIAN MIR, 1901-1903.

PART I.

SUMMARY OF THE OPERATIONS ANTECEDENT TO THOSE WITH WHICH THIS REPORT DEALS.

THE operations at Mian Mir and the conditions under which they were carried on have been described in previous reports,* but it will not be out of place to briefly refer to their main features. The operations were intended to demonstrate the reduction of malaria in a cantonment by measures based upon recent knowledge of the ætiology of this disease, and as started by the Royal Society's Commissioners, together with Captain James, I.M.S., were primarily directed against mosquitoes. There were many reasons at the time why this method of prevention should have first consideration. Not only did the reduction of the number of *anopheles* appear to be the most complete and satisfactory of all measures, but it was a method of malarial prophylaxis concerning which nothing was as yet known of the ease or difficulty with which it could be carried out. In the course of their researches in Africa, the Commissioners had become doubtful of the practical value of operations against mosquitoes in the moister regions of the world. But in the semi-desert conditions prevalent in North India, and especially in the Punjab, they saw what appeared to them to be the proper sphere for such operations. A cantonment in the North-West of India which offered the best conditions for the experiment was therefore sought for. But most cantonments which appeared to be favourable for operations were comparatively healthy, whereas those at which high admission rates for malarial fever were constantly recorded were generally found to be unfavourable for operations. The more malarial stations for troops in North-West India, as shown by the admission rates for intermittent fever, are :—

Station.	Admissions per mille; average for years 1896-1900.
Delhi	1,145·6
Ferozepore	760·6
Mian Mir	663
Meerut	477·2
Fatehgarh	464·4
Amritsar	445·6
Fort Allahabad	400

* Reports to the Malaria Committee of the Royal Society, by J. W. W. Stephens, M.D., S. R. Christophers, M.B., and Captain James, I.M.S., 8th series. October 1902.

First Report of the Anti-Malarial Operations at Mian Mir, 1901-1903, by Capt. S. P. James, I.M.S., Scientific Memoirs by Officers of the Sanitary and Medical Departments of the Government of India (new series), No. 6.

It is important to note that, on examination, each of these stations was found to possess some serious drawback to the carrying out of successful anti-mosquito operations. Delhi Fort was found to be in close proximity to the native town of Delhi as well as to an extensive tract of sand and water in the bed of the Jumna. Ferozepore was found to have extensive waters not far removed in the bed of the Sutlej River. Even in Mian Mir, which was eventually chosen, it soon became evident that the presence of irrigation in this cantonment was a condition much more unfavourable to operations than had been anticipated. But on the whole Mian Mir appeared to be best adapted to the carrying on of the experiment, and the conditions seemed sufficiently favourable to allow of a marked success being achieved in the fight against malaria. This cantonment, however, covered an area of about 12 square miles, and only a portion was therefore chosen for the experiment. The selected area was, to a large extent, isolated from the rest of the cantonment. It contained the barracks of the Royal Artillery, a large and some small native bazaars, officers' bungalows and their gardens, and was representative of most cantonments in North India. About three-quarters of the cantonment was left untouched, and this part, being under the same physical conditions as the chosen area, formed a valuable control in all operations.

The experiment was commenced in September 1901, but actual operations were not undertaken until April 1902, since the first six months were devoted to a thorough investigation into the conditions present. At the time when the investigation was commenced, little was known as to the breeding-places of *anopheles*. It was customary to discuss points of biology as relative to the whole genus *anopheles*, and considerable discussion still took place as to the presence of *anopheles* larvæ in this or that situation. The work of Stephens and Christophers[1] and of Daniels[2] in Africa, James[3] in India, Grassi[4], Nuttall[5], and others in Europe had gradually made it evident that *anopheles* were not so restricted in their breeding-places as was at first supposed. Immediately prior to the experiments at Mian Mir, it had also been shown by Stephens, Christophers, and James, that individual species of *anopheles* frequented particular kinds of breeding-places, and that one or other species bred in almost every possible kind of collection of water, even in foul water (*A. Rossii*) and in pots,

[1] Stephens and Christophers. Reports to the Malaria Committee of the Royal Society, 1st, 6th and 7th series.

[2] Daniels. Reports to the Malaria Committee of the Royal Society, 3rd series.

[3] James. Ind. Med. Gazette, Dec. 1899.

"Malaria in India." Scientific Memoirs by Officers of the Medical and Sanitary Departments of the Government of India. New series, No. 2.

[4] Grassi. *Studi di uno zoologo sulla malaria. Secunda edizione, note-volmente accrescinta,* October 1901.

[5] Nuttall, Cobbett and Strangeways-Pigg. Journal of Hygiene. Vol. I, No. 1.

earthenware vessels, etc. (*A. Stephensi*). In Mian Mir the irrigation channels were found to be a prolific source of *anopheles*. Larvæ were found in the shelter of grass or fringing vegetation even in the more swiftly-flowing channels, whilst they swarmed in many of the sluggish, weed-containing ones. The interesting discovery was made that the larvæ in the canals were almost entirely those of a single species, *viz.*, *A. culicifacies*. Pools formed by rain were also found to swarm with larvæ, but these were, with rare exceptions, those of *A. Rossii*. Earthenware vessels, fire pots, and other utensils, though not important sources of *anopheles*, were interesting as containing larvæ of *A. Stephensi*. A few species, quite rare in comparison with the two species mentioned above, *viz.*, *A. juliginosus*, *A. nigerrimus*, and *A. pulcherrimus*, bred in a few grassy and weedy pools in the surrounding country. The two species *A. culicifacies* and *A. Rossii*—the former breeding in the canals and the latter in rain-formed pools—were of most importance in Mian Mir.

From the researches of the Commission in Bengal it had already appeared that *A. Rossii* was a species whose presence did not appear to bear much relation to the prevalence of malaria. *A. culicifacies*, on the other hand, resembled in its adult, egg, and larva states, as well as in its habits (*i.e.*, the selection of running water for breeding), a number of mosquitoes of which the African species *A. funestus* is the type, which have been shown to be actively concerned in the spread of malaria and to be associated with a high malarial endemicity. The importance of these facts led us to dissect large numbers of each species both in Mian Mir and in Ennur—a highly malarious village in the Madras Presidency. The glands of 850 specimens of *A. Rossii* were examined without sporozoits being found, whereas these bodies were detected in the glands of 18 out of 328 specimens of *A. culicifacies*. In Mian Mir it thus appeared that *A. culicifacies* was the species mainly concerned in the transmission of malaria, and that the canals required the first consideration.

Experiments had appeared to show that the presence of larvæ in the canals was largely dependent upon a sheltering fringe of vegetation, and that removal of this greatly diminished their numbers. The first operations, therefore, which it was decided to undertake were:—

(1) A thorough cleaning of all irrigation water-courses within the area and within a distance of half a mile beyond its limits.

(2) The conversion of one canal which passed close to each of the three barracks, the quarters for families, the hospital and prison, into a brick channel.

The conditions during the rains were at this time imperfectly known. It was evident, however, that a large number of pools must be formed. It was also probable from several considerations that these pools were the main breeding-places of *A Rossii*. Though the pools appeared to be of less importance than

the canals, it was nevertheless decided to undertake vigorous operations against them, and to add to the above :—

(3) The filling-up of as many as possible of the pits which abounded in the area, and during the rains the pouring of kerosine oil on all breeding-places which could not be permanently done away with.

A very important feature in the area was the presence of certain bazaars. An examination of the children in these revealed a very high degree of infection, and infected *anopheles* were caught in the houses in large numbers. A large bazaar—the Royal Artillery bazaar—was situated within 400 yards, and no less than three smaller native communities within 150, 400 and 400 yards, respectively, of the barracks. It was, therefore, recommended that—

(4) One of the syce lines situated at a distance of only 150 yards from the barracks should be moved to a greater distance. The parasite rate in the children of these lines was then 56 per cent.

Operations were actually commenced in April 1902 and continued by Captain James, I.M.S., for a period of over a year. Fifty coolies were at first employed to clean the sides of the canals which were much overgrown with vegetation. When all the canals in the area had been cleaned, a smaller number of men were kept permanently at work on them, removing fallen leaves and other *débris*, and plastering the sides with mud. As a result of these operations the canals in the area were converted into clean channels of water with little or no shelter at the edges for larvæ. Captain James notes that up to the beginning of June the cleaning appeared to be a very effective measure, and that larvæ were less numerous in the cleaned canals than in others. Later in the season, however, the efficiency of the operations was not so marked. In the initial experiments it was evident that sufficient attention had not been given to the more sluggish water-courses in which, in spite of the thorough cleaning of the banks, larvæ became abundant. . The brick-lined canal, which, it is fair to state, was one of the most sluggish in the area, also contained many larvæ during the later months of the year. The general result of the cleaning operations went to show that where the flow of water was sluggish, cleaning of the edges of the water-courses, though hostile to larva development, did not prevent the breeding of *anopheles*. In channels, especially the main *rajbahas*, where the flow of water was considerable, cleaning of the banks was most effective, and larvæ were rarely seen in cleaned channels of this nature.

In addition to the cleaning operations, Captain James tried the effect of shutting off the water and drying the watercourses, also of oiling the canals with kerosine oil, and the latter course he found most practicable.

During the rains, in addition to the work on the canals, a great deal had to be done in connection with rain-formed waters. The operations were of great

interest since they gave some idea as to how far the conditions at this time could be influenced. The rainy season in Mian Mir is very short and the rainfall not great. Nevertheless, as Captain James points out, the ground is very impervious, so that rain water readily collects in shallow pits or even upon the flat ground. He notes the following as the main additional breeding-places in the rains:—

1. Shallow and extensive sheets of water.
2. Surface drains in which water lies after rain.
3. Rain-filled pits.

The shallow sheets of water shrink very rapidly, but residual pools are left which had to be drained, baled out, or treated with oil. Water in surface drains was similarly treated. *The most difficult of all the breeding-places to control at this time were the rain-filled pits.* Some idea of the number of these may be gathered from the fact that Captain James records 137 as present within the area after a fall of rain of two hours' duration. Of pits of this nature 250 were filled with earth before October 1902 and many more were systematically oiled during the rains.

In addition to the work on the canals and rain-filled pits, the most careful examination of the whole area for breeding-places, and their destruction when found, was carried out. Pools in connection with Persian wheels—the apparatus for raising water from the canals—were found a fruitful source of *anopheles* and were periodically oiled. Collections of waste water and many other miscellaneous sources of *anopheles* were systematically destroyed.

Such were, in the main, the anti-culicidal operations carried out by Captain James from April 1902 to the end of the fever season in that year. It would seem strange if they had not an effect upon the number of adult *anopheles* in the area. Yet the results were by no means as great as might reasonably have been expected. *Anopheles* were evidently still quite abundant in the bazaars, and regarding *A. Rossii* Captain James could note no difference in the numbers as compared with the previous year. With regard to *A. culicifacies* he notes that they were present, but in diminished numbers, so that the treatment of the canals had appeared to be more effective than that of the rain-formed waters.

On the whole we have the somewhat startling fact that in spite of most energetic operations having been carried out continuously for many months, in which the whole of the canals had been cleaned, 250 pits filled with earth, and large numbers of other breeding-places destroyed by oil, the reduction in adult *anopheles* was at the most very slight.

With regard to the effect of the operations upon the malaria of troops, it

was unfortunate for the outcome of the experiments that the year 1902 was an exceptionally healthy one for all troops in the Punjab. Though a very small number of admissions for malaria occurred among the Royal Artillery, an equally small number occurred among the British Infantry, who lived in a portion of the cantonment where no operations had been carried on. Moreover, Captain James notes that during the Delhi manœuvres many changes took place among the men of the Royal Artillery, and concludes that where so many factors affected the statistics it was impossible to obtain results of value from their consideration. On the endemic indices of the bazaars, however, Captain James notes a distinct effect as following upon the operations. In his figures for the indices of the different months a most marked reduction is seen in August and September. In a later portion of the present report a similar result is noted for 1903, and it appears certain that the low figures for these two months were the direct outcome of the operations, since in neither case was there anything like the same small rate in the control bazaar or in the same bazaars in the previous year. In October 1902 the amount of malaria, however, had increased to such an extent in the children of the Royal Artillery bazaar as to nearly equal that in the control bazaar. On the whole Captain James concludes that the fever season had been delayed and shortened in the bazaar as a result of the operations.

We can then summarise the main results of the first year's work as follows :—

1. Cleaning of the banks in itself did not prevent the breeding of *anopheles* in the water-courses, and in addition oiling with kerosine oil was found necessary.

2. The breeding-places of *A. Rossii* were extremely abundant during the rains. The breeding-places within the area were, however, almost entirely destroyed by filling up or oiling.

3. Adult *A. culicifacies* were to some extent diminished, but in the case of *A. Rossii* no reduction was noticeable.

4. The fever season in the bazaar was delayed and shortened. In the case of the troops no deductions could be made on account of changes among the men at the time of the Delhi manœuvres.

Although the value of several other means of prophylaxis was investigated by Captain James, I shall here draw attention only to an attempt during the cold season of 1902-03 to destroy *anopheles* over a wide area. It was found by him that in the cold weather both adults and larvæ of *A. culicifacies* became extremely scanty. He also found that no new batches of eggs were deposited during this time, and that when the larvæ which seemed to be hibernating were destroyed in any pools, no new ones appeared. As adults were not to be found by the most exhaustive search, he concluded that this species hibernated in the larval form, and he hoped, by the destruction of the hibernating larvæ over a wide area, to cause a diminution in the numbers of *anopheles* in the on-coming warm season.

The operations were, however, without effect, and in May 1903 *anopheles* were as abundant as ever.

The results of the operations directed against *anopheles*, in spite of the thoroughness with which they were carried out, cannot be regarded as very encouraging, and Captain James, in his concluding remarks, is distinctly of opinion that as far as the first year was concerned the operations were very far from being an unqualified success.

PART II.

Operations from July to November 1903.

THE operations dealt with in the present report were carried on from July 1903, and included the rains from the 15th of July to the 11th of September, and the fever season from August to November. They afforded the opportunity of a second estimation of the value of the operations.

On the whole the operations were similar to those in the previous year. But as the canals had been cleaned and a large number of pits filled, it was possible to still further extend the area of the operations against rain-formed breeding-places, and this was done to a distance of nearly three-quarters of a mile in every direction. At the same time the greatest care was taken that no breeding-places were left nearer at hand, and the various sections of the area were carefully gone over at short intervals. The whole area of the operations extended over about four square miles, and is shown in the map which accompanies this report.

The physical conditions of Mian Mir, and especially the conditions in relation to malaria in this cantonment, have been sufficiently described in Part I, and it will not necessary to do more than describe the operations as they were carried out in the present year. These operations may be very conveniently divided into—

1. Those connected with the irrigation water-courses.
2. Those dealing with a variety of sources of *anopheles* of small extent, such as stone reservoirs, waste water, and other casual collections of water.
3. Those directed against the rain-formed pools.

Except in cases of emergency, coolies employed on the canals were kept on this work, since they had learnt exactly what was required of them. With regard to the second series, very little coolie labour was required, since breeding-places of this kind were not difficult to destroy once they were detected. A fresh gang of about 30 coolies was engaged for work during the rains only.

I.—Operations upon the water-courses.

The sides of the canals in July were very smooth from the constant "plastering" and larvæ were rare even in the more sluggish channels. Larvæ, however, were not abundant in untreated canals at this time. In August, larvæ began to be abundant in the canals, especially in a long canal near the large Royal Artillery bazaar, not very far from the extensive lines of the Native Cavalry. As at this time the cleaning of the sides seemed to be quite ineffective in stopping the increase in the number of larvæ, "oiling" was resorted to. In the

present year the whole of the canals in the immediate area and to a distance of half a mile, or a little less in some cases, were oiled, and the process repeated at first every week and later at intervals of 12 days. The latter time was determined by experiment (see time of development of larvæ in Mian Mir, page 23), and was the time taken for larvæ to become full grown but not to pupate. After the institution of this regular oiling *nymphæ were caught with the greatest rarity in the channels so treated.*

As it was found necessary to employ "oiling" even after cleaning of the banks, it was important to determine whether kerosene might not be employed directly upon uncleaned canals. Experiments, however, showed that the presence of vegetation in water very greatly interfered with the destruction of larvæ by oil, and in some cases abundant larvæ were found after oiling such waters, in the cases of both canals and pools. Fringing vegetation, as it occurs in most of the untreated canals in Mian Mir, was found to render effective oiling impracticable. Ordinary cheap kerosene oil was used and was spread by means of a watering pot. The cost of effective oiling was found to be, in channels $1\frac{1}{2}$ yards in width, about Rs. 4 to the mile. As the total length of canal oiled was roughly 4 miles, and as some of the channels were rather wider than the above, the monthly cost of oiling was about Rs. 30 to Rs. 40.

Experiments with emulsion of kerosene oil.—As the spreading of kerosene oil seemed to be the only satisfactory way of treating the canals, it became important to reduce as far as possible the cost of the process, and to see if similar results could be obtained with a smaller quantity of oil by modifying the method of application. It was found that kerosene oil readily emulsified when shaken with soap solution. It was also found that oil so emulsified spread much more uniformly upon water and required no mechanical agitation to distribute it. In experiments in the laboratory on pure water containing larvæ (*anopheles*) the following results were obtained:—

	After 15 minutes.	After 1 hour.
1 c. c. pure oil per 100 sq. c. water . .	All dead.	———
·5 c. c. „ „ „ „ „ „ . .	Many living.	Some still living.
·25 c. c. „ „ „ „ „ „ . .	No marked effect.	A few dead only.
·125 c. c. „ „ „ „ „ . .	No effect.	No effect.
1 c. c. oil in emulsion per 100 sq. c. water .	All dead.	———
·5 c. c. „ „ „ „ „ „ „ .	All dead.	———
·25 c. c. „ „ „ „ „ „ „ .	No marked effect.	About half larvæ dead.
·125 c.c. „ „ „ „ „ „ „ .	No effect.	No effect.

By emulsifying kerosene oil, therefore, its effectiveness is almost doubled, the difference being due to the much more perfect film produced. The cost of the soap and the small amount of labour necessary (the oil readily emulsifying) may be neglected, and a saving in the amount of oil used is effected. In experiments in which pure oil and half the quantity of emulsion were used on canals the pure oil was found to be somewhat more effective, so that in actual practice the difference was not so marked, and on the whole it was found most convenient to use ordinary oil. Under certain circumstances, however, the emulsion might be used with benefit, especially where very large amounts of oil are used, or where it is desired to prevent the oil being taken for other purposes than those intended.

Although, after each oiling, larvæ in a canal were found to have completely disappeared, yet within two or three days young larvæ were always found to be present. As the season advanced, larvæ in the canals, and especially in certain portions of these, became more and more abundant in spite of the oiling. It appeared at this time that adult *culicifacies* were increasing in the area in spite of the operations.

Several times during the season the water of the canals was shut off for a variable number of days. On these occasions the water remaining in the canal was at first baled out, but the process was not persevered with, since the water was readmitted before the mud became dry, and experiments had shown that larvæ could remain alive a considerable time even upon mud that was nearly dry (see notes on the biology of mosquitoes in Mian Mir, Part IV). At the time when the water was cut off and consequently lying very low in the canal, it was usual to find larvæ in much greater numbers. The explanation at first seemed difficult, but appeared to be that with the fall of the water larvæ were washed out from numerous Persian wheels and other *cul-de-sacs*, and, passing beneath the syphon bridges, entered the canals in the area. Whenever, therefore, the water was shut off, the residual waters were oiled. From October the water in the canals was shut off for ten days or more at a time. When such an opportunity occurred, the whole of the canals in the area were baled out, and became quite dry. Unfortunately at this time larvæ were diminishing in numbers and the fever season was nearing its end.

II.—Miscellaneous breeding-places.

In the next section it will be seen that by drainage and filling up, all pits and sheets of water were removed from an area of about a square mile immediately around the barracks, bazaar, and bungalows. In spite of this, however, a good many small breeding-places were still left which required to be searched for and destroyed. Larvæ were found in small cement tanks in connection with wells and with garden irrigation, also in waste water from large wells and other

in the land, both brick and earth drains are liable to remain full of water, and in some of the latter larvæ of *A. culicifacies* were found.

Perhaps the most noticeable and important feature of Mian Mir in the rains is the presence of numbers of "rain-filled pits." In the building of every native hut, the making of walls, rifle butts, and other structures, it is the practice to dig earth from the ground somewhere in the neighbourhood. The result is the formation of a large number of pits varying from a few feet in diameter to 50 yards or more, and from one to ten feet in depth. In the more central area these pits were, as a rule, small and not very numerous, but near the cantonment limits they occur in hundreds and under natural conditions swarm with the larvæ of *A. Rossii.*

A. Superficial drainage.—In spite of the difficulty of ensuring a sufficient fall for drainage, it was found possible with some care and thought to drain the surface waters from almost the whole area. Within an area of about a square mile immediately around the bazaar and the barracks, over 50 sheets of water were permanently drained by earth-cut channels, and required no further attention throughout the rest of the season. Most of these required only a broad shallow channel to be cut in the line of greatest fall. In some cases, by making rather large drains, whole systems of pools could be drained into them and ultimately into the canals. The most important of the drainage operations were carried out to the south of the bazaar, where an extensive series of large sheets of water was drained into the canals. In this case treatment by drainage appeared at first sight impossible, and had this been so the large marshy pools would have defied almost any treatment, since long grass and other vegetation grew luxuriantly, and made "oiling" a very uncertain and expensive measure. Eventually two long drains, each nearly a quarter of a mile long, and a number of collateral drains effectually removed the whole of the water. In many cases, when a drain had been dug through a pool, the ground, instead of remaining muddy and full of puddles due to the trampling of oxen and men, became hard and dry within a few hours of the cessation of rain.

On the whole, surface drainage was found, even in Mian Mir, the most effective and satisfactory of all the operations. Very little labour was required to carry it out, and, once established, the whole area became automatically dry within 24 hours of the heaviest rain.

B. Filling with earth.—Although surface drainage was so efficient in the case of rain-formed surface pools, it could not be used for the rain-filled pits already mentioned. In this case several methods of preventing the breeding of *anopheles* were employed. Naturally the best way of dealing with these was to fill them up again with earth or rubbish. It has already been noted that 250 such pits were filled during the period that the operations were under the

direction of Captain James. There remained, however, within the area undertaken at least an equal number more, and as the filling of these was a work of great magnitude, only those pits in the more central area were filled during the present operations. In endeavouring to fill a large number of pits in so flat a country as Mian Mir, difficulty arises as to the source from whence the earth with which to fill them can be obtained. Most of the pits in the present instance were filled by earth taken from old rifle butts and a disused brick kiln. In filling pools it was found advisable to fill them to a higher level than the surrounding ground, since subsidence takes place after a time and a new pool reforms on the site of the old. In some cases pits were purposely only partially filled, since rain does not at first collect in these owing to the porous nature of the freshly laid down earth. Such pits are, however, liable at any time to become breeding-places and require to be constantly watched.

In some cases very large pits were only partially filled, in order that the operation of "baling-out" might be more readily performed.

C. Baling-out.—In the account of the rains it will be seen that, especially between the later downpours, intervals of as much as a fortnight occurred. Under these conditions the process of baling out the water from pits was found a very satisfactory one. Directly after a downpour of rain attention was concentrated upon the more central area, and all water lying in the brick and earth drains was removed by men with empty paraffin tins. At first these operations took at least five days to complete, but after the draining of the superficial sheets and the filling of the pits, a much less time, at most two days, was required. By the the time that operations in the central area were finished a partial sinking of the water in the pits of the outlying area had occurred, and the delay of a few days was thus advantageous, since it lessened the amount of water to be removed. In numerous observations as to the time of development of *A. Rossii* in deep and shallow pools it was found that pupæ were never formed before the twelfth day after the formation of a pool. Twelve clear days were thus given in which baling-out operations could be carried on, provided, that is, no second shower of rain fell in the meantime. The time of the next rain was of course never known, so that baling operations were carried on as actively as possible, and the whole area was gone over in about eight days. If at any time rain threatened before all the pits were baled out, those remaining were at once oiled, since, as noted before, a fall of rain on pits already full of larvæ was to be avoided.

The pits, some idea of the number of which may be gathered from the map, were of various depths and extent. As a rule, they held, a few days after rain, from 100 to 400 gallons of water. There were, however, certain large excavations which became filled with water (Group B) and contained some thousands of gallons. At the commencement of the operations these were oiled, since to empty

them occupied several days. Later, however, when operations had been simplified by many small devices, it was found possible for twelve coolies to empty them in a single day. In baling out water, devices for hastening the process may be very advantageously employed. The large pits just mentioned, which contained water over 10 feet in depth, were first partially filled by tearing down the earth at their sides. The result of this was to enlarge their area, but to greatly diminish their depth. A channel with a deep hole at the end was then dug in order to bring the water to the edge of the pit, where it was baled out with ease by relays of two men at a time. In some cases a double channel had to be formed in order to lift the water to the desired height. In others two channels were made to enable relays of four men to operate. By making a few small "*bands*" water was prevented from flowing back into the pit. Once the coolies employed in baling out realised the great saving of labour to be obtained by such devices, they showed much ingenuity in applying them.

The operation of baling out appeared to be particularly adapted to operations at the end of the rains. In the present instance within ten days of the cessation of the last rain the whole of the pits in the area were rendered free from water and thus eliminated as breeding-places. The only groups shown in the map not so treated were the Group P. and some few others to be noted in the next paragraph, which required different treatment.

D. "*Oiling.*"—In the early part of the season most of the pits in the outlying area were not generally baled out, since the rain fell at too frequent intervals to make this a practicable measure. In order to prevent breeding in these they were therefore "oiled" by pouring just sufficient kerosene from a watering pot to destroy the larvæ. A very good test of the efficacy of the oiling was the appearance of immense numbers of dead water beetles and other insects on the surface of the water. Unfortunately the great importance of some of these outlying pits, most of them at a distance of half a mile, was not at first recognised, so that it was only from the end of August, when larvæ were found swarming in them, that actual measures were adopted. (See occurrence of adult *A. Rossii* in area, Part IV.)

Oiling, both in the case of pits and canals, was always certain in its results where no vegetation existed. The cost, if used indiscriminately for all breeding-places, was considerable, and in order to employ it to the most advantage, it was, if possible, used when pits were reduced in size by drying, but before pupæ were found. The Group M. (see map) on the 4th of September, eleven days after rain, consisted of 50 water-containing pits and required only about 6 gallons of oil. On the 11th of September, soon after rain, the same group consisted of nearly 100 pools, some of large size, and 15 gallons of oil had to be used. Had all the pools in the area been oiled weekly, about 200 gallons, costing Rs. 50, would be

required per month. This is less than the cost of wages to coolies for baling these out, so that, except at the end of the rains, oiling would appear to be the most suitable means to adopt against pools of the above nature when these cannot be permanently obliterated by filling them with earth. There were in the area two large wells used by washermen, the waste water from which was allowed to sink into the ground. After a time the ground became so saturated that the whole area in the neighbourhood of the wells was boggy and full of innumerable puddles. Such collections are shown on the map at V and IV. At IV it was found possible to conduct the waste water into a large drain and so to dispose of the pools. At V, however, it was impossible to drain the area, and since larvæ of *anopheles* and *culex* swarmed in the puddles in spite of the foulness of the water, oiling had to be resorted to. The water was, however, almost hidden in the grass, and oiling was found quite ineffective unless very large quantities of oil were used. In order that the oiling might be effective, it was in this case necessary to have most of the grass scraped away by coolies.

PART III.

RESULTS.

IN order to test the efficacy of the operations it is well to discuss separately :—

I.—The effect upon breeding-places and upon the number of larvæ.

By the permanent removal of some breeding-places and the constant destruction, by oiling and other means, of all others, the whole area of four square miles had, to all appearances, been rendered free from breeding-places of *anopheles*. It is, of course, impossible to say with absolute certainty that no breeding-places were overlooked. The greatest care was, however, taken to examine at short intervals every part of the area, and as the operations had been in progress for some time, most of the land was very accurately known, and large numbers of places where breeding-pools might occur were noted. The only point to be regretted was that some groups of pools in the outer circle were not attacked sooner. All these pools were at such a distance (over half a mile) that at the time their importance was not realised. It is believed, however, that no breeding-places escaped attention in the more central area from July onwards, and very few in the outer area from the end of August.

In the operations the destruction of larvæ was enormous. A single oiling of a canal in the later months must have destroyed millions, since it was not unusual to remove fifty or more specimens in a single dip of the dipping can. In the pits also, where larvæ were often so abundant as to give the appearance of a scum, the repeated oiling and baling out must have accounted for vast numbers. It appears almost certain that a very small proportion of larvæ in the area were allowed to hatch out after the end of August, when periodical oiling of the whole canal system and destruction of the outer circle of breeding-places was commenced. It would certainly appear likely that after such destruction larvæ would recur in lessening numbers. It was surprising, therefore, to find that within a few days of every oiling, whether of a canal or a pit, an undiminished and even increased swarm of young larvæ were present. The presence of the larvæ undoubtedly depended upon that of adults in the area, for there was much evidence to show that the eggs were laid *in situ* and were not to any extent carried down stream from outside the area. This was shown in the case of a small length of canal forming a *cul de sac*, and especially noticeable as containing large numbers of larvæ after each oiling. A "*band*" was made across the entrance from the main canal and the whole oiled. In spite of no fresh water being admitted, larvæ were in a few days present in large numbers. The

number of larvæ in the area, in spite of repeated wholesale destruction, showed no tendency to diminish.

II.—The effect upon the number of adults.

It has been already noted that two species, *A. culicifacies* and *A. Rossii*, were the common *anopheles* in Mian Mir, and that the habits of each were markedly different. In the period devoted to research a very fair idea of the prevalence of these in the different bazaars was arrived at. It was, however, impossible to give any accurate measure of their numbers, since so much depended upon the facilities for seeing them. Of *anopheles* in general, it may be said that they are difficult of detection and require concentrated attention on the part of the searcher, if they are not to be overlooked. *A. Rossii*, however, is a mosquito fairly easy of detection, and it is possible to employ comparative terms, for their numbers, such as "swarming," "abundant," "scanty," "found with difficulty," or "not found at all." In the case of *A. culicifacies* it is harder to arrive at any definite idea as to their numbers. This species is extremely careful to secrete itself, and if there are no suitable collecting places, it may very easily be considered absent when in reality it is abundant. Should, however, a low-roofed, rather dark shed be available, adults are usually caught readily. With regard to this species then we can only say that "it was caught readily by looking in suitable places," or that "a few specimens only were to be caught," or that "they were not found."

In the saddle rooms adjoining the stables of the Royal Artillery, adult *anopheles* were particularly easy of detection, since they were found resting on the inner surface of the hanging saddles. On the 19th July 1903 search in these rooms did not reveal a single adult. On the 8th September 1903 *A. Rossii* were abundant. On the 27th September 1903 *A. Rossii* were swarming, *A. culicifacies* were fairly abundant, and specimens of *A. fuliginosus* and *A. pulcherrimus* were not uncommon. In the bazaars in the area exactly the same conditions occurred. On the 17th July 1903 no adults were seen after a long search in the Royal Artillery bazaar. On the 5th September 1903 *A. Rossii* was abundant and *A. culicifacies* was readily caught. Occasional specimens of *A. fuliginosus* and *A. pulcherrimus* were also found.

Whether *A. culicifacies* was diminished in September in the bazaars and saddle rooms it is very difficult to say for the reasons noted above. With regard to *A. Rossii*, however, it is quite certain that no perceptible diminution whatever had occurred.

The outcome of our experiment in regard to the effect of anti-culicidal measures against *anopheles* is therefore at direct variance with the results of such operations as have been hitherto recorded. It is but fair, however, to

add that in many of such recorded operations no attempt whatever was made to show by search in the houses that the number of *anopheles* was really diminished. In the present experiment operations against the larvæ might have been considered most successful if the destruction of breeding-places only was taken count of, or if popular opinion as to the presence of mosquitoes was considered evidence. It was, for instance, common in the present year to hear that mosquitoes had almost disappeared. The remark was, however, as often made by people living outside the area as by those within, and in any case referred obviously to *Stegomyia* which, from its habit of biting in the day, calls special attention to itself. (See operations against *culex*.)

I may here call attention to some experiments directed against the breeding-places of *culex*. In the course of the periodical examination of the bungalow section, attention was given to the breeding-places of *culex* (*C. fatigans*, *S. sugens*, and *S. fasciata*), and a large number of collections of waste water, and water in tubs, tins, and especially in pots were oiled or emptied. All stray tins or pots were inverted, broken, or removed. By these operations—which required little or no labour—the number of breeding-places was greatly reduced. Though no means were taken to show whether *culex* adults were much diminished by these means, yet from a number of observations I was led to surmise that *Culex fatigans* and *stegomyiæ*, especially the former, were much more readily reduced in numbers than were *anopheles*. Close by the Royal Artillery barracks there were, for instance, a number of shallow earthenware pots used for horses. A long row of these was left unused and became filled with rain after each downpour. There were, moreover, no other breeding-places for *culex* found in the immediate neighbourhood. In the beginning of the season larvæ of *C. fatigans* and *Stegomyia sugens* abounded in the majority of the pots. The pots were then regularly emptied within a few days of each fall of rain. After four weeks, when again allowed to remain for some time full of water, most of the pots were free from larvæ. The few larvæ which were found, were those of *S. sugens*.

In my own bungalow it was also possible, by attention to all small breeding-places, to prevent mosquitoes being troublesome. A neglect of such precautions was always followed by their presence in troublesome numbers. But although the bungalow was in a very isolated position and its surroundings, including the servants' quarters, readily examined, it was found impossible to quite do away with mosquitoes, and stray specimens were constantly caught. On the whole, I believe that operations against *culex* mosquitoes are followed by much more distinct results than those directed against *anopheles*. Both *culex* and *stegomyiæ*, however, appear to find their way in small numbers to houses in spite of the strictest care being taken to prevent them breeding in the neighbourhood.

III.—The effect upon malaria.

The aim of the experiments was in the first place the demonstration of a reduction in malaria among troops. For many reasons, however, troops do not form a very suitable community upon which to measure the effect of such operations. In the first place the figures of returns for malaria admissions are extremely variable,* so that it is impossible to tell whether in any year a very small figure is due to natural causes or to hygienic measures. From the following table it will be seen how difficult it is to draw any conclusion from the yearly admission rate as to the effect of the experiment in 1902. The figures for the Royal Artillery were in that year certainly lower than in any previous year, but at the same time the reduction in the number of admissions among the British Infantry (untreated area) was even more marked:—

Year.	Strength.		Admissions.		Admissions per thousand.	
1898	All troops, 869		702		808	
1899	„ „ 853		400		469	
1900	Royal Artillery, 259	814	132	878	509	1,079
	British Infantry, 555		746		1,344	
1901	Royal Artillery, 225	808	346	1094	1,538	1,354
	British Infantry 583		748		1,283	
1902	Royal Artilery, 172	731	66	197	384	269
	British Infantry, 559		131		234	

It also seems certain that the health of any given body of troops in any particular year must depend not only upon the conditions then present in the station (number of *anopheles*, infection, etc.), but also upon the state of the regiment as regards the number of old infections, unseasoned men straight from home, men from malarious stations, and so on. Moreover, not only are statistics complicated by the movements of the men (as in the case of the Delhi Manœuvres in 1902), but they are liable to depend very largely upon a personal equation, since great differences exist in the degree of illness considered by different medical officers as necessitating admission to hospital. The coming on duty, for instance, of a medical officer who admits even slight cases of undoubted malaria, may double the admission rate for this disease. On the other hand, slight cases may be only "detained," not admitted, and the admission rate thus lowered.† On the whole, then, the number of admissions for malaria among troops do not form the best test of the effect of operations.

* The figures for a number of years are given by Captain James in the first report, page 6.
† "Detained" cases are not shown in the official returns.

I have previously mentioned the presence in the area of several native communities, *viz.*, the regimental bazaar, the syce lines and hospital followers' lines. The people living in these, especially the children, form a much more suitable community for testing the efficacy of the operations than the troops. It is, however, obvious that if by mosquito destruction operations the health of native communities is improved, the station is also rendered more healthy for troops. In discussing the effect upon malaria we may therefore notice :—

(*a*) *Native malaria.*—A comparison between malaria in the bazaars within the area and malaria outside the area as evidenced by the endemic indices, appeared to show that in spite of the poor results as regards adult *anopheles*, a distinct effect was produced upon malaria. During August and September of the present year the endemic index of both the Royal Artillery bazaar and the hospital followers' lines remained phenomenally low, being 0 and 4, respectively. The spleen rate was however higher in proportion, being 36 per cent. and 41 per cent. respectively. During the same months malaria in the British Infantry bazaar was much as in other years, the spleen rate being 70 per cent. and the endemic index 30. This highly satisfactory state of affairs was unfortunately not maintained throughout the season, and it was found impossible to prevent the rate in the bazaars from rising in October and November. In these two months the endemic indices in bazaars in the area were high and apparently quite uninfluenced by the operations. We shall see later that all our results pointed to the same conclusion, namely, that by the operations the onset of the fever season was postponed, but that after the first two months no effect upon malaria was apparent.

Table showing spleen rates in bazaars within and outside the area of operations :—

		September.	October.	November.
Royal Artillery bazaar (in area).	Spleen rate . .	36·6	64·5	64
Hospital followers lines (in area).	Spleen rate . .	41	60	60
Syce lines . . . (in area).	Spleen rate . .	45	67·5	54
British Infantry bazaar (outside the area).	Spleen rate . .	70	77·5	77

(*b*) *Malaria among troops.*—An exactly parallel effect to that on malaria in bazaars appeared to be produced upon the malaria of troops. Among the British Infantry (who lived outside the area) men began to be admitted to hospital early in August, the number of admissions for this month being 29 out of a total strength of 477. In September malaria was still more prevalent, the admissions being 92. Among the Royal Artillery, admissions were very infrequent in August, being only 5 out of a strength of 240. In September the admissions numbered only 19. So far then the difference between the two bodies of troops was very striking. But later on malaria became much more frequent among the men of the Royal Artillery, the admissions being 88 for October out of a strength of 277, and 122 for November out of a strength of 285. The British Infantry were at this time less affected with malaria, the admissions being 89 for October out of a strength of 476, and 201 for November out of a strength of 723. In these two months quinine was, however, administered under very strict supervision to the British Infantry, and the lowered rate of admission might well be due to this cause. The total numbers of admissions, from 1st July to the end of November, were in the case of the British Infantry 416 and in the Royal Artillery 234, the average monthly strengths being 448 and 264 respectively. These figures give 158 per mille per month as the admission rate for malarial fevers among the British Infantry and 216 per mille per month as the admission rate for malarial fevers among the Royal Artillery, the difference in the figures for the whole season being therefore somewhat in favour of the British Infantry, who, as already mentioned, lived outside the area of operations.

PART IV.

Certain Points in the Biology of Mosquitoes noted during the Anti-Malarial Operations.

THE species of *anopheles* found in Mian Mir have so far been—

1	*Anopheles Rossii* (Giles).		[=*Myzomyia Rossii.* Theobald].
2	„	*culicifacies* (Giles).	[= „ *culicifacies.* Theobald].
3	„	*Stephensi* (Theobald).	[=*Nyssorhynchus Stephensi.* Theobald].
4	„	*fuliginosus* (Giles).	[= „ *fuliginosus.* Theobald].
5	„	*pulcherrimus* (Theobald).	[=*Cellia pulcherrima.* Theobald].
6	„	*barbirostris* (Van der Wulp).	[=*Myzorhynchus barbirostris.* Theobald.]
7	„	*minutus* (Theobald).	[= „ *minutus.* Theobald.]

It has already been mentioned that *M. Rossii* and *M. culicifacies* were the common species and that the former bred in the rain-formed pools and the latter in the canals and that, apart from such sources, these species were rarely found. With regard to *N. fuliginosus*, it was noted that occasional adults occurred in the bazaars and stables, but that the larvæ were only to be found in certain "grassy" pools, of which there were about a dozen in the area. It was a curious fact that though the larvæ of both *M. Rossii* and *M. culicifacies* were found in these pools they occurred only in very small numbers. The only source of *N. fuliginosus* was the outlying area, and in no case within 1,000 yards of the situation where the adults were captured. This species is undoubtedly a comparatively "wild" species and breeds by choice in pools with much algae, lake margins, etc. The occurrence of *N. fuliginosus* in such small numbers was the more noticeable, since in the Central Provinces (Nagpur) and some other parts of India where breeding-places of the above nature abounded, this species was very numerous. The markedly wild species *M. barbirostris* were caught only in the larval state and on the extreme limits of the area where water with much vegetation occurred, and its adults were never seen in the bazaars. *M. barbirostris*—so common in some parts of India—appeared unable to propagate itself in the muddy pools and canals of Mian Mir. Adults of *C. pulcherrima* were caught in small numbers all over the district, within and without the area. The larvæ of *N. Stephensi* were mostly to be caught in "pots," but occurred also in stone reservoirs, and sometimes in shallow and small pools.

The *Culicidæ* * other than *anopheles* found in Mian Mir were—

Stegomyia fasciata.
„ *sugens* (Wiedmann).
„ *scutellaris* (Walker).
Culex fatigans (Wiedmann).
„ *impellens* (Wiedmann).
„ *concolor* (Desvoidy).
„ new species.
Tæniorhynchus tenax (Theobald).
„ new species.
Melanoconion, new species.
Howardina, new species.
Mucidus scataphagoides.

Of these *S. fasciata*, *S. sugens* and *C. fatigans* were very common household mosquitoes and formed the bulk of the "culex" occurring in the bungalow section. *C. impellens* and *Melanoconion* were extremely abundant species in the outlying area, being found in almost all natural waters except the muddy rain pools. *Tæniorhynchus* occurred in a few grassy and weedy waters. Adults were caught mostly in the hospital followers' lines, half a mile from the nearest known breeding-place (Groups E. and G. See map.)

The larvæ of both *C. concolor* and *M. scataphagoides*† are actively cannibal, living entirely upon other larvæ. *C. concolor* was almost everywhere present in pots, whereas the larva of *mucidus* was very common in natural waters. From the frequency with which the larvæ of both species were found, the part played by them in keeping down other species of mosquitoes must be considerable.

The most noticeable phenomena in regard to mosquitoes in the present season were :—

I.—The swarming of certain species, both anopheles and culex, during a comparatively short period, so that their numbers were quite out of proportion to those found at other times.

Of all the species *M. Rossii* exhibited this "swarming" phenomenon in the greatest degree. In July, larvæ of *M. Rossii* were practically never seen, the only *anopheles* then found breeding being *M. culicifacies*, which was limited to the canals. Even for some time after the onset of the rains no larvæ were found in the numerous pools then formed. By the third week after the first fall of rain, pools containing larvæ (*M. Rossii*) were found more readily, and by the sixth week such

* Kindly identified by Mr. Theobald.
† See a later paper on the larval characters in relation to the classification of the Culicidæ.

pools were abundant. By the middle of September the larvæ of *M. Rossii* had increased in numbers enormously and swarmed in the pools around the bazaars. They were also to be found in the large majority of pools throughout the whole country side, as well as in countless shallow puddles lying in the furrows of arable land. At this time, no matter how far from habitations search was made, the larvæ of *M. Rossii* were always readily found. By the end of September the breeding-places of this species had become much reduced, from the drying up of the more shallow pools, and a few weeks later the breeding-places were localised to a few spots where water still remained. The adult insects showed a corresponding increase, and though before the rains found with the greatest difficulty, they were to be caught in immense numbers in every bazaar and village in the neighbourhood a few weeks later. They remained in large numbers in spite of the reduction in breeding-places until the end of October, and then rather rapidly disappeared.

Tables showing increase of M. Rossii in August and September. Observations in British Infantry Bazaar.

LARVÆ.

Day after first shower of rain.	Number of pools in immediate neighbourhood.	Extent to which larvæ were present.
7	6	No larvæ found.
21	8	Abundant larvæ in one pool.
42	17	Larvæ abundant in 6 pools.
58	26	Larvæ present in every pool, swarming in many.

ADULTS.

Day after first shower of rain.	Number of adults in bazaar.
7	2 Specimens found after long search.
21	Adults very scanty.
42	Anopheles very abundant (M. Rossii).
58	M. Rossii "swarming."
98	Numbers of M. Rossii much reduced.

This increase in the numbers of *M. Rossii*, from a species difficult to obtain to one swarming in every situation, is undoubtedly due to the formation by the rains of abundant breeding-places suitable for the species. The extremely small number of larvæ of this species in the first week or two of the rains goes to show that at the end of the dry weather adults had almost disappeared. The enormous increase during the later rains and ending when the rain pools have

become dry is then a very striking feature in the life history of *M. Rossii.* Such a time of swarming is not confined to the Punjab, for in several parts of India we have observed a similar phenomenon.

In July, larvæ of *M. culicifacies* were not abundant. Even uncleaned canals contained very few whilst the cleaned ones were remarkably free from larvæ. An increase, however, in the number of the larvæ in the canals began to be noticed in August, and they increased steadily throughout September and abounded in both cleaned and uncleaned canals in October. They then underwent a striking diminution and almost disappeared with the onset of the cold weather in November. The adults of *M. culicifacies* appeared to outlast those of *M. Rossii* and captures of *anopheles* in the middle of November contained more specimens of this species than of *M. Rossii*, a reversal of the conditions prevailing earlier in the season when *M. Rossii* was caught far more readily than *M. culicifacies.* In the case then of *M. culicifacies* there also occurred a very marked increase at this time. The increase in *M. culicifacies*, however, could not have depended upon an increased area of breeding-place, though the conditions may have been rendered more favourable by a copious addition of rain water to the canals. It is also worthy of note that the numbers of *M. culicifacies* reached their maximum in October, whereas at this time *M. Rossii* was diminishing. On the whole the period of greatest prevalence of *M. culicifacies* corresponded more closely with the highest incidence of malaria than did that of *M. Rossii.* This is in keeping with what has been previously noted in regard to the relation of these two species to malaria.

Rather late in the season *N. fuliginosus* and *C. pulcherrima* became more common in the area and appeared to share in the general increase in September and October. The occurrence of *N. fuliginosus* at this time was peculiarly significant, since all grassy pools in which the larvæ were detected had long been dried out. *Specimens of this species must almost certainly have flown in from beyond the limits of the area.**

Other *Culicidæ.*—Certain species of "culex" exhibited in a marked degree the "swarming" phenomenon. A species of the genus *Howardina* occurred in vast numbers during the period of heaviest rain. They appeared to occur in single broods, one after each downpour of rain. Pupation appeared to occur in all larvæ on the same day, and the extensive shallow pools in which they bred lasted as a rule only sufficient time to allow the pupæ to hatch.

II.—The flight of anopheles over considerable distances.

A most important series of observations made on *anopheles* were those relating to the distances they can fly. In every case the conclusion was that

* Also see the first report of the operations, page 37.

where an abundant food-supply existed *anopheles* travelled long distances ($\frac{3}{4}$ of a mile or more) to reach it, and that they traversed an equal distance if necessary to lay their eggs. Where, however, a suitable breeding-place lay near at hand they did not appear to pass it over. It has been already noted that the larvæ of *M. Rossii* swarmed in pools immediately around bazaars, villages, etc. In the height of the *anopheles* season such pools often contained so many larvæ that they appeared, when looked at from a short distance, to be covered with a scum. Around the edges of these pools also the ova were so abundant as to form a distinct black line. Such a state of affairs was, however, never seen under natural conditions at any great distance from a large food-supply. But after all breeding-places had been destroyed in the neighbourhood of the Royal Artillery bazaar by the drainage or filling-in of all pools, larvæ were found in enormous numbers in distant pools at T and M (see map). In order to determine exactly how far *anopheles* will fly under these circumstances the above-mentioned pools were all dried by baling out the water. The result of this measure was that larvæ then swarmed in the pools of groups S, and N, where previously they had been present only in small numbers. That the larvæ in these pools were derived from adult *M. Rossii* coming from the bazaar was certain, and the flight of *anopheles* over a distance of $\frac{3}{4}$ of a mile was therefore demonstrated.

Very abundant adult *M. Rossii* were found during August in the saddle rooms in connection with the Royal Artillery stables. By this time all breeding-places in the neighbourhood had been drained or filled up, and the pools at A, B, and F, had been regularly controlled by oiling or baling out. Larvæ at this time were swarming in the pools at C, though not in some pools still further away. As adults continued to increase in the saddle rooms, they undoubtedly came from the pools at C, the nearest pool being 900 yards distant.

We must then look upon the maximum distance to which *anopheles* (*M. Rossii*) will fly as not yet known. Under the conditions at Mian Mir, however, the above experiments show that they fly to and fro a distance of at least half a mile.

In has been already remarked that adults of *N. fuliginosus* were not uncommon in the bazaars, stables, etc., and this in spite of the fact that larvæ of this species only occurred on the extreme limits of the area. In the case of *N. fuliginosus* there also appears to be a very considerable power of flight. With regard to *M. culicifacies* it is also difficult to see where the adults came from in the later part of the season unless distances of half a mile or more were traversed by this species.

It is important, before leaving this subject, to briefly note what appear to be the conditions influencing the flight of *anopheles*. That *anopheles* do not fly long distances without good reason is most likely, and from many observations it is our experience that the abundance of the food-supply is the factor deter-

mining the presence of *anopheles*. It is indeed only under very exceptiona circumstances that a crowded community in the tropics is free from *anopheles*. In the Nagpur district, $\frac{1}{4}$ of a mile was found by Stephens and Christophers * to be readily traversed by *anopheles* in passing between their breeding-places and villages. In this locality, however, the distance of half a mile appeared to put a considerable check upon their presence. In Mian Mir, on the contrary, *anopheles* appeared to traverse half a mile as readily as shorter distances. The distance travelled in Mian Mir, however, was over a bare plain with little or no obstruction to the passage of light or sound. We believe indeed that it was largely on account of the extremely flat and open nature of the country around Mian Mir that such long distances were traversed by *anopheles*. Further experiments upon this point are, however, of the utmost importance.

III.—The spread of adult anopheles.†

During the course of the experiments it was found that *anopheles* breeding-places formed very often a complete circle around the bazaar or other situation in which the adults occurred. When, by means of the operations, the distance of breeding-places was increased around the Royal Artillery bazaar, it was found that *anopheles* did not all lay their eggs in the nearest pools but that they often flew in directions necessitating much longer distances being traversed than was necessary. The only explanation of this fact appeared to be that *anopheles*, when searching for breeding-places, spread in all directions and continued flying until a suitable breeding-place was found. Although at one time the pools at T were available for breeding, swarms of larvæ appeared in the groups M, P, and K (*vide* map).

Such a habit would explain the spread of adul t*anopheles* from areas where breeding-places are abundant into such an area as that under consideration which had been artificially rendered free from breeding-places. Every large source of food-supply would indeed be an agent for disseminating adults *in all directions*. Taking into consideration the number of such disseminating centres in and around the area, *i.e.*, bazaars, native lines and servants' quarters, it is not so very surprising that the operations were ineffective in preventing the final occurrence of adults in the area. From a variety of reasons we believe that an infiltration of adults took place mainly in the following ways :—

1. Spread from servants' quarters outside the area to neighbouring quarters within the area and from these to others still more centrally situated.
2. Spread from the native cavalry lines, which were unfortunately only 1,000 yards distant.

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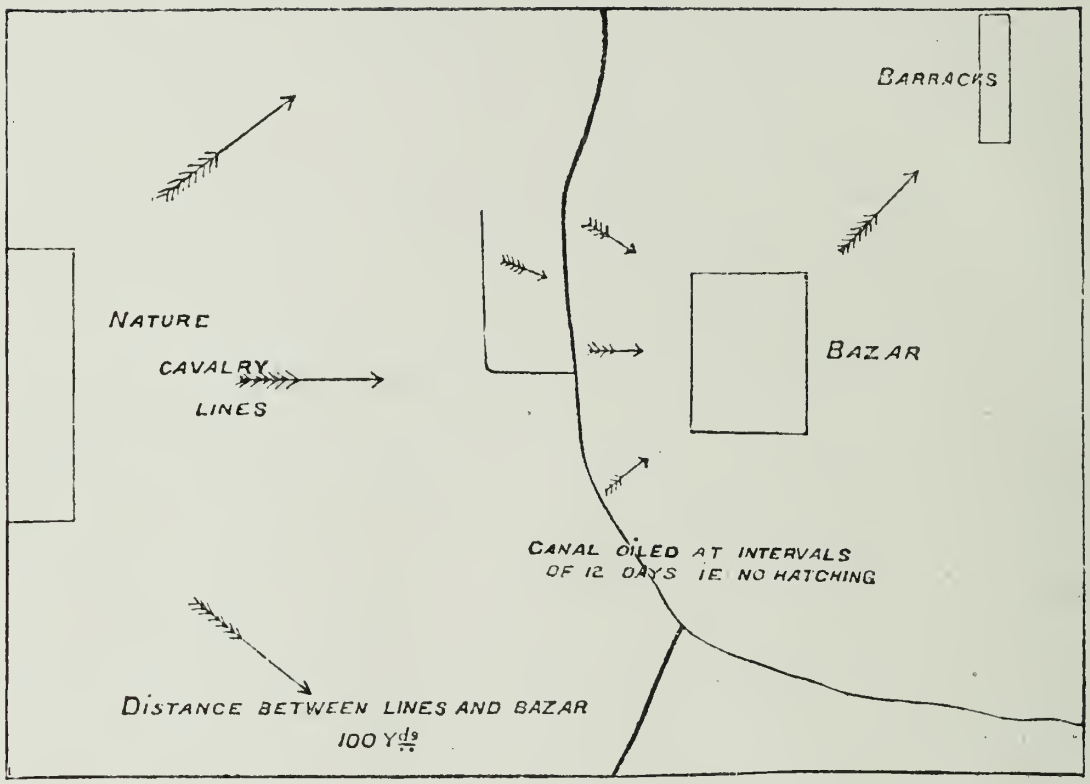
* "An investigation into the factors which determine malarial endemicity." Reports to the Malaria Committee of the Royal Society, 7th series.

† See also the first report of the anti-malarial operations, page 37.

3. By flight over the open plain surrounding the area on the south and east aspects.



Showing infiltration of adult anopheles into an area. The large arrows indicate flight in search of breeding-places; the short arrows flight towards lights, sounds, etc., after eggs have been laid.

Reference has already been made to a portion of canal in which larvæ were especially abundant. This lay between the Royal Artillery bazaar and the Native Cavalry lines, but considerably nearer to the former. It appears probable that in the radiating flight from the Cavalry lines a number of *anopheles* would reach this canal, but having laid their eggs, would as readily fly to the Royal Artillery bazaar as to the more distant Cavalry lines. Thus no amount of oiling of this portion of the canal would prevent *anopheles* using it as a means of reaching the Royal Artillery bazaar. (See the above diagram shewing the method of infiltration of adult *anopheles* into an area.)

That *anopheles* adults are constantly changing their feeding and resting place is rendered very evident by the remarkably constant sporozoite rate in *M. culicifacies*. It matters little in this respect from which house, shed or stables this species is taken, since the percentage of infected individuals is much the same in all places.

IV.—The time of pupation and hatching of mosquitoes in Mian Mir.

Numerous observations on pools under natural conditions showed that *M. Rossii* did not pupate before the twelfth day. The observations were made in September when there was much hot sunshine and the nights were warm. No difference in the rate of development was noted in the case of shallow or deep pools, although the temperature of the water in the very shallow pools was very high during the day, 95° F. to 102° F. In the deeper pools the water was much cooler, 90° F. or less. Adult *M. Rossii* hatched out two days after pupation. Fourteen days appeared therefore to be the minimal time in which adult *M. Rossii* hatched in September. As this month appeared especially favourable for the development of this species, it is probable that the above represents the shortest time in which *M. Rossii* can develop.

Observations upon canals showed a very similar period for pupation of *M. culicifacies*. The minimal time in which nymphæ appeared in a freshly filled canal being thirteen days.

Considerable differences existed in the time of pupation and hatching of the different genera of mosquitoes. Species of the genus *Stegomyia* hatched with marvellous rapidity, pupating on the eighth day and hatching on the tenth. Of all the genera *Anopheles* was the slowest in developing, taking three days longer than *Culex* and four days longer than *Stegomyia*.

Table showing the time of pupation and hatching of some mosquitoes under natural conditions in September.

Date.	Day after first filling of pools or pots.	Weather.	Pupation.	Hatching.
6th September 1903 .	1st	First shower after 15 days drought.	None.	None.
7th „ „ .	2nd	Hot sunshine.	„	„
8th „ „ .	3rd	Rain.	„	„
9th „ „ .	4th	„	„	„
10th „ „ .	5th	„	„	„
11th „ „ .	6th	„	„	„
12th „ „ .	7th	Hot sunshine.	„	„
13th „ „ .	8th	„ „	*Stegomyia.*	„
14th „ „ .	9th	„ „	*Culex.*	„
15th „ „ .	10th	„ „	None.	*Stegomyia.*
16th „ „ .	11th	„ „	„	*Culex.*
17th „ „ .	12th	„ „	*Anopheles.*	*Mucidus.*
18th „ „ .	13th	„ „	None.	None.
19th „ „ .	14th	„ „	„	*Anopheles.*
20th „ „ .	15th	„ „	„	None.

V.—Observations in regard to deposition of ova and their resistance to desiccation.

Various observations have been made in regard to the resistance to desiccation of ova of *anopheles*. Christophers and Stephens, as well as Nuttall, Cobbett, and Strangeways-Pigg, found that ova allowed to dry upon blotting paper for a few days did not give rise to larvæ on the addition of water. The former observers also note that no larvæ appeared on the addition of water to earth taken from the bottom of twenty-five small, dried, *anopheles* rock pools. Gray also got negative results with earth taken from a dried-up pool. Liston* described the hatching at once on the addition of water of ova which had remained several days on mud not quite dry. I was able to confirm this observation of Liston's with ova taken from the bottom of partially dried up pools in Mian Mir. Ova could be detected in some cases even when the mud had been quite baked in the sun. They did not, however, appear ever to be laid on mud in this condition, but were laid readily on mud which, though cracked from drying, was still moist. Ova were laid daily on mud so long as signs of moisture were present, but once the whole pit had become thoroughly dry no further ova were deposited. In many cases pits, even before becoming thoroughly dry, were overrun by ants, and ova were never found under these circumstances.

Ova were searched for on mud of various degrees of dryness, and when found were removed and placed carefully on water. The results are noted in the following table :—

Character of mud.	Number of ova taken.	Number hatched in 15 minutes.	Number eventually hatched.
Quite soft	12	0	12
Cracked but moist . .	10	2	8
Quite dry	25	5	1
Slab of soft mud with ova dried 12 hours in sun.	A large number.	0	0

Ova of *M. Rossii* laid during the night of the 21st September 1903 and placed in a small natural pool exposed to sunshine, became young larvæ on the morning of the 24th. Other observations on ova also gave about this time (48 hours) for the hatching of the larvæ. Eggs laid upon mud, therefore, appear to undergo development and to hatch out at once on the addition of water. From this cause many larvæ must be present on the very first day of rain and the hatching of the adults anticipated, by 48 hours.

* Liston, *Ind. Med. Gazette*, Dec. 1901.

VI.—The effect of heavy rain upon anopheles larvæ.

On several occasions when pits containing *anopheles* larvæ were examined a short time after rain, it was found that all the larvæ had disappeared. At the same time larvæ were found 50 to 100 yards away in innumerable small puddles left by the rain. Since these larvæ, from their large size, could not have developed *in situ*, it was evident that they had been washed out of the larger pits and distributed over the ground. After one shower nineteen large pits were observed to have been emptied of larvæ in this manner and the larvæ were found scattered over the ground.

VII.—The effect of desiccation on anopheles larvæ.

When the above-mentioned puddles dried, it was easy to determine how long larvæ resisted desiccation, by pouring some water on to the site of puddles of varying degrees of dryness, and observing the results. In most cases larvæ could be seen immovably fixed in the surface film of mud. These, however, liberated themselves on the addition of water, even when they had been exposed to the sun for some hours. When, however, the mud had so far dried as to lose its glistening surface, the larvæ were destroyed.

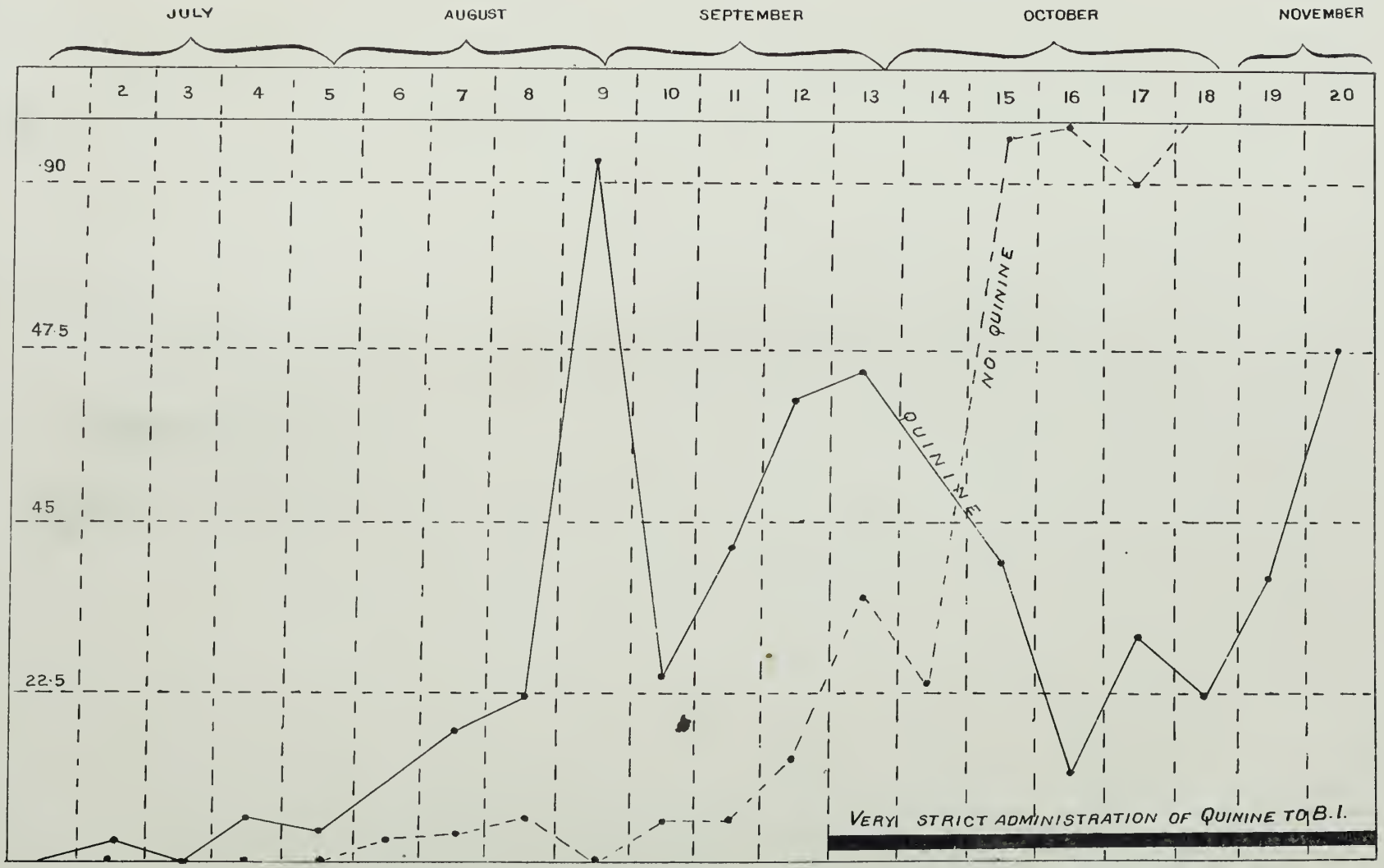
PART V.

QUININE ADMINISTRATION.

IN addition to operations against mosquitoes, experiments were made in regard to the efficacy of quinine administration to British troops, native troops and the native children of the followers' lines. In all cases where adults were concerned a dose of 15 grains of quinine was given on two consecutive days weekly. In the case of native children proportionate doses were given. Consecutive days were chosen, since, in the majority of cases, double infection with the benign tertian parasite was found.

Quinine, when employed as a prophylactic against malaria, is usually distributed to British troops through non-commissioned officers. It was our experience, however, that by such a method of administration a very small proportion of the men really took any quinine. Unfortunately it was found impossible to get a satisfactory method of administering quinine to large bodies of men. Even when the men were mustered and a roll called, many were found absent on various duties. On the whole, except in very special cases, administration of quinine to large bodies of men was always more or less imperfect. It will be necessary, in order to arrive at any conclusion as to the value of quinine administration, to consider the experiments under three heads.

(*a*) *Experiments limited to a small number of men where quinine was administered with scientific accuracy.*—One hundred men among the British Infantry volunteered to take quinine regularly. A list was made of the men's names and a mark placed for each dose of quinine taken in my presence. Of the hundred men 95 had taken six doses of quinine up to the 1st September. The results of this experiment were very marked. It was very noticeable that after a man had taken four doses of quinine he did not get malaria. Two doses of quinine was not apparently effective, since several of the 100 men who had received two doses were admitted for ague. Of those men who, after the first four doses, continued to take the drug regularly, only two were admitted to hospital for malaria. In neither case, however, were parasites found on examination. Among the remaining 353 men there had been in the same period 71 admissions for malaria. In 50 per cent. of these cases parasites were found by Captain Sewell, R.A.M.C. Between August 25th and September 15th the admissions from the men taking quinine were 21 per mille as against 201 per mille from those not taking quinine. From 29th September the whole of the British Infantry were placed under strict quinine treatment, and the smaller experiment ceased.



Black line = British Infantry (outside the area)
Dotted line Royal Artillery (within the area)

(*b*) *Administration to large bodies of men under very strict conditions.*—The taking of quinine was made compulsory and a roll of each company was kept on which was entered each dose of quinine taken. The men were paraded and the administration of the quinine was carried out under the supervision of a medical officer. The administration was on the whole very thorough, but it was found impossible to be sure of men who were absent on various duties. These were supposed to take quinine on returning to barracks, but it was of course impossible to be certain that they did so. Compared with the results in the first experiment the effect of quinine administration was disappointing. Coincident with the institution of the quinine administration, there was, however, a distinct fall in the admission rates (*see* chart showing weekly admissions). The admissions in each week from 1st July to the 10th November in the British Infantry and the Royal Artillery were as follow. The asterisk indicates strict quinine administration :—

Weeks .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Royal Artillery .	0	0	0	0	0	1	1	2	0	2	2	4	12	7	26	26	24	36	31
British Infantry .	0	1	0	3	2	5	7	10	41	11	19	26	* 29	* 24	* 18	* 5	* 14	* 10	* 16

The strength of the British Infantry was considerably greater than that of the Royal Artillery, and on the whole a very distinct reduction in malaria appeared to follow the administration of quinine upon these lines.

(*c*) *Quinine administered without supervision or under regimental supervision.*—In every one of the experiments of this kind not the slightest effect was evident. In the case of the native cavalry quinine was given under regimental supervision to all but two squadrons. The admissions were greater among those supposed to be taking quinine than among those not doing so. In this and similar experiments it was found impossible to maintain adequate supervision even when the administration was supervised by a regimental officer, and it is extremely uncertain how many of the men really received quinine regularly.

We may say then that the experiments very clearly showed that the effect of quinine administration to troops depended entirely upon the care and strictness with which it was administered. In the experiment with a limited number of men any man not taking quinine as intended was not included in the results, and the action of quinine was most clearly demonstrated. In actual practice it

is almost certain that such a thorough giving of quinine would be found extremely difficult. In the case of the experiment dealing with the British Infantry the administration of quinine was made, it is believed, as thorough as is possible except under very special circumstances, and here although the results were not to be compared with those in the smaller experiment, a very distinct reduction in malaria appeared to take place. As a routine practice, under conditions existing at present, we do not believe quinine administered to troops is of much value. Could, however, very much more stringent regulations be brought to bear upon the carrying out of this measure, quinine appears to be a most effective means of lowering the fever rate.

The Administration of Quinine to Native Children.

Attention has several times been called to certain native quarters situated in the neighbourhood of the Royal Artillery barracks. Early in the operations it was recommended that one of these (syce lines), within 150 yards of the barracks and at a less distance from the hospital and prison, should be removed to a greater distance. Another much larger source of infection existed in the regimental bazaar which, at the time, was considered too large to remove. Since then, however, the Government of India have taken steps to have this bazaar pulled down and re-erected at a safe distance. In the case of the syce lines there were certain objections to their removal, and since they formed a comparatively small community, experiments were instituted by Captain James as to the possibility of treating all the children with quinine. The results obtained by him were satisfactory, and similar experiments with regard to this point were carried out in the present year. In the early part of the season a generally low rate of infection prevailed among the children in the area. Towards the end of September a rapid rise in the endemic indices of the different bazaars was noticed. At this time then it was thought that a good opportunity for the demonstration of the value or otherwise of the administration of quinine to these children existed. No difficulty was found in getting all the children in the lines to take the drug. A list of all the children was obtained from the Cantonment authorities and a gift of native sweets made to each child after taking the quinine. To my surprise the children readily took large doses (5 to 10 grains) and did not complain of any symptoms of cinchonism. The effect upon the spleen rate was very distinct, as is shown in the following tables. During October the spleen rate in these children was reduced from 67·8 per cent. to 54 per cent. In the Royal Artillery bazaar, the children in which had not received quinine, the rate remained high, *viz.*, 64·5 per cent., as also in the hospital followers lines, *viz.*, 60 per cent. Looked at in detail the results were still more striking. A glance at the accompanying tables will show that in nearly every case in which the spleen

was enlarged it was reduced in size by the treatment, whilst in many cases enlargement of the organ was no longer perceptible.

Table showing the effect of one month's administration of quinine to native children.

Children.	Spleen before taking quinine.	Spleen after taking quinine.	
1	1 finger's breadth below costal margin	Just palpable	Decrease.
2	4 fingers' „	2 fingers' breadth	Decrease.
3	*Nil*	*Nil*	
4	*Nil*	*Nil*	
5	Reaching to umbilicus	Reaching to pubes	Increase.
6	3 fingers' breadth	*Nil*	Decrease.
7	*Nil*	*Nil*	
8	*Nil*	*Nil*	
9	*Nil*	*Nil*	
10	Just palpable	Just palpable.	
11	3 fingers' breadth	1 finger's breadth	Decrease.
12	3 „ „	1 „ „	Decrease.
13	2 „ „	*Nil*	Decrease.
14	1 finger's „	1 finger's breadth.	
15	1 „ „	1 „ „	
16	2 fingers' „	2 fingers' „	
17	*Nil*	*Nil*	
18	4 fingers' breadth	1 finger's breadth	Decrease.
19	1 finger's „	Just palpable	Decrease.
20	1 „ „	*Nil*	Decrease.
21	Just palpable	*Nil*	Decrease.
22	1 finger's breadth	*Nil*	Decrease.
23	3 fingers' „	2 fingers' breadth	Decrease.
24	*Nil*	*Nil*	
25	3 fingers' breadth	2 fingers' breadth	Decrease.
26	3 „ „	2 „ „	Decrease.
27	*Nil*	*Nil*	
28	*Nil*	*Nil*	
29	1 finger's breadth	1 finger's breadth.	
30	3 fingers' „	*Nil*	Decrease
31	*Nil*	2 fingers' breadth.	Increase.
32	Just palpable	Just palpable.	
33	3 fingers' breadth	3 fingers' breadth.	
34	*Nil*	1 finger's „	Increase.
35	Just palpable	1 „ „	Increase.
36	1 finger's breadth	*Nil*	Decrease.
37	*Nil*	*Nil*	

PART VI.

General Conclusion.

THE conclusions arrived at by myself are in close accordance with those expressed by Captain James, I.M.S., in the first report. It has, however, in many cases been possible to confirm and render these more certain. We may tabulate what has been demonstrated in the Mian Mir operations as follows:—

1. The destruction of *anopheles* within an area by attacking their breeding-places is extremely difficult. Although large numbers of pools were filled up and drained, and millions of larvæ destroyed by oil, adult *anopheles* were still abundant.

2. The mere obliteration of local breeding-places is useless. In Mian-Mir almost complete absence of breeding was ensured to a distance of over half a mile, but adults still appeared in large and in increasing numbers in the area.

3. A distinct effect was produced upon the malaria of troops and on the endemic index of the bazaars. This was, however, only evident in the beginning of the fever season, and could not be maintained.

4. The failure of the operations appeared to be due to the passage of adult *anopheles* into the area from without. This went on steadily during October when breeding-places were not present in the area, and it could not be prevented.

5. The value of quinine administration was found to depend entirely upon the degree of supervision exercised. Experiments showed that where the men really took quinine regularly the admission rate for fever was much reduced.

6. The operations further demonstrated the necessity of removing bazaars and followers' lines to a distance. Experiments undertaken with the view to rendering small collections of native followers innocuous by treating the children with quinine were very successful. Where small native communities, especially servants' quarters, cannot well be removed, the regular administration of quinine to children is a prophylactic measure of great value.

It is significant that some effect upon malaria was produced by anti-mosquito measures, but as regards Mian Mir it is evident that the operations undertaken were unable to effectively control the incidence of malaria among the troops. It is our opinion that, although the operations yielded a great deal of information and showed what difficulties must be taken into account, they were not those best adapted to the eventual reduction of malaria. The latter we believe to be such gradually carried out sanitary reforms directed against malaria as are indicated by careful investigation into the conditions present in cantonments. At Mian Mir, for instance, there are several features

which can be unhesitatingly denounced as tending to foster malaria. These cannot be removed at once, but their gradual removal is in most cases, we believe, possible. In the experiments efforts were made to obtain immediate results, and the permanent removal of widespread insanitary conditions was not attempted. It is possible that the conditions in Mian Mir were more difficult of control than in some other cantonments. We have, however, no certain knowledge of the conditions in other cantonments, and until a detailed examination and careful mapping of these has been carried out, it is impossible to say how far measures directed against malaria based upon these lines are likely to be successful. With regard to quinine administration we think the difficulty of maintaining efficient administration will prevent this measure from being of much use as a routine one. Moreover, it appears to us that gradual but permanent improvement in the health of stations by well-directed sanitary reforms, wherever these can be carried out, will in the end yield the best return.

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